

SISKIYOU SUMMIT NEGATIVE GRADE ARRESTER BED
FOR RUNAWAY TRUCKS

Experimental Feature Project OR 77-02
Final Report

by

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INTRODUCTION

Long downgrades often cause trucks to lose their brakes and go out of control, creating a hazardous stretch of roadway with an abnormally high accident rate. In an attempt to prevent these accidents, three principle methods are currently employed: signs to alert drivers of long descents, brake test areas at the beginning of descents, and escape ramps.

Most escape ramps are designed to use gravity as the primary deceleration mechanism. These ramps provide an exit from the roadway to an adjacent hillside, ascending at grades of up to 40%. Loose gravel is often used on these ramps which, while aiding in the deceleration, is primarily provided to prevent the trucks from rolling back down the ramp. Unfortunately, ascending ramps are not possible in all locations where they are needed. This report presents the results from a special type of escape ramp, a ramp that is located on a descending grade.

BACKGROUND

On northbound Interstate Highway 5, approximately 4.5 miles north of the Oregon - California border, is seven miles of 5.0 to 6.4 percent downgrade. Due to a record number of accidents involving runaway trucks on this portion of highway, a truck escape ramp was proposed by the Oregon State Highway Division to be included as part of a pavement overlay and safety improvement project.

The terrain to the right of the northbound lanes drops away steeply, and with a very narrow median strip, a site for an ascending slope arrester bed was not readily available. Several alternatives were considered for constructing an ascending ramp, including a fill on the right side, a bridge over the highway to a slope on the southbound side, and switching northbound and southbound lanes so that the northbound would be next to an ascending slope. Each of these three alternatives was determined to be uneconomical or impractical and was dropped from consideration.

When an ascending ramp proved infeasible, it was decided to design and build a descending escape ramp on the existing minus 5.6% grade. A testing program was established to determine if a descending grade gravel arrestor bed, including transverse gravel mounds, could safely stop a runaway truck. The testing was divided into three segments: choosing aggregate size and gradation, testing the effect of gravel transverse mounds, and on-site testing of the escape ramp prior to its opening for use by the public.

RESEARCH AND DESIGN

Several parameters had to be considered in determining a suitable aggregate specification. In order to provide adequate rolling resistance, the wheels of a vehicle using the ramp must sink into the gravel. For this to occur, the aggregate must be rounded and uniformly sized to prevent consolidation. Also, because the Siskiyou site is subjected to freezing temperatures, the chosen aggregate must drain freely to prevent its freezing into a solid mass. Based on these considerations, laboratory tests were conducted to determine an optimal aggregate specification.

Two different gradations of gravel were tested, a 3/4-3/8 inch and a 3/8-#10. Penetration tests showed the smaller gravel had slightly higher penetrability, and therefore, slightly better rolling resistance. To test the effects of freezing, the gravels were placed in a test cylinder, flooded with water, drained and frozen. Compression tests on these frozen samples revealed a distinct advantage to the larger size gravel. Since the risk of disaster was high if the arrestor bed froze, the specifications were written for the 3/4-3/8 inch gradation. These specifications were later modified to 3/4-1/2 inch because there were excessive elongated particles in the gravels available for this project (see Figure 1).

The use of a series of transverse mounds of gravel was suggested to increase the effectiveness of the escape ramp. Theoretically, as a truck strikes a gravel mound, energy is transferred from the truck into the gravel and the truck decelerates more rapidly. Successful implementation of this concept requires that the truck not careen out of control or be damaged as it strikes the mounds.

In an earlier report detailing a series of tests run at Camp Adair, near Corvallis, Oregon, the effect of gravel mounds was studied. Mound heights of 1, 2 and 2 1/2 feet, spacings of 14 and 30 feet, and test vehicle speeds of 25 and 40 mph were tested. Although the mounds did slow the test vehicles, the reactions of the vehicles were more violent than expected, occasionally resulting in tie rod and axle damage. This report (1) recommends that mounds not be used unless there are no safer alternatives.

(1)

HPR Study 5149-15 "Energy Absorption of Gravel Mounds for Truck Escape Ramps" by Gordon Beecroft, Research Engineer, Oregon State Highway Division, March 1978.

FIGURE 1

SISKIYOU TRUCK ESCAPE RAMP AGGREGATE PROPERTY REQUIREMENTS

	12-7-76 (letter)	12-22-76 (job specs)	2-23-77 (PA #2)
Degradation			
passing #20, max	30%	30%	30%
sediment ht, max	3"	3"	3"
Abrasion LAR, max	30%	30%	30%
Sand Equivalent, min	68	68	68
Grading			
passing 1"	100%	-	-
3/4"	85-100%	100%	100%
1/2"	-	25-50%	0-15%
3/8"	0-15%	0-15%	-
1/4"	-	-	0-5%
Shape factor	Dimensions	12% Max	X
P 3/4"-R 1/2"	1 1/8" max x 3/8" min	exceed	X
P 1/2"-R 3/8"	3/4" max x 1/4" min	max/min = 2	X
Crushing			
max crushed faces	1%	10%	10%
		"natural" crush only	"natural" crush only

*NOTE:

The 12-7-76 Recommendations were based on samples received which were supposed to be representative. The 12-22-76 (job specs) recommendations were the result of further testing. Price Agreement No. 2 deleted the shape factor requirement and tightened the gradation.

Final gradation:	Passing 3/4"	100%
	1/2"	0-15%
	1/4"	0-5%

*from William Maude's office, 4-11-79

ON SITE TESTING

The four main objectives of the on site testing were:

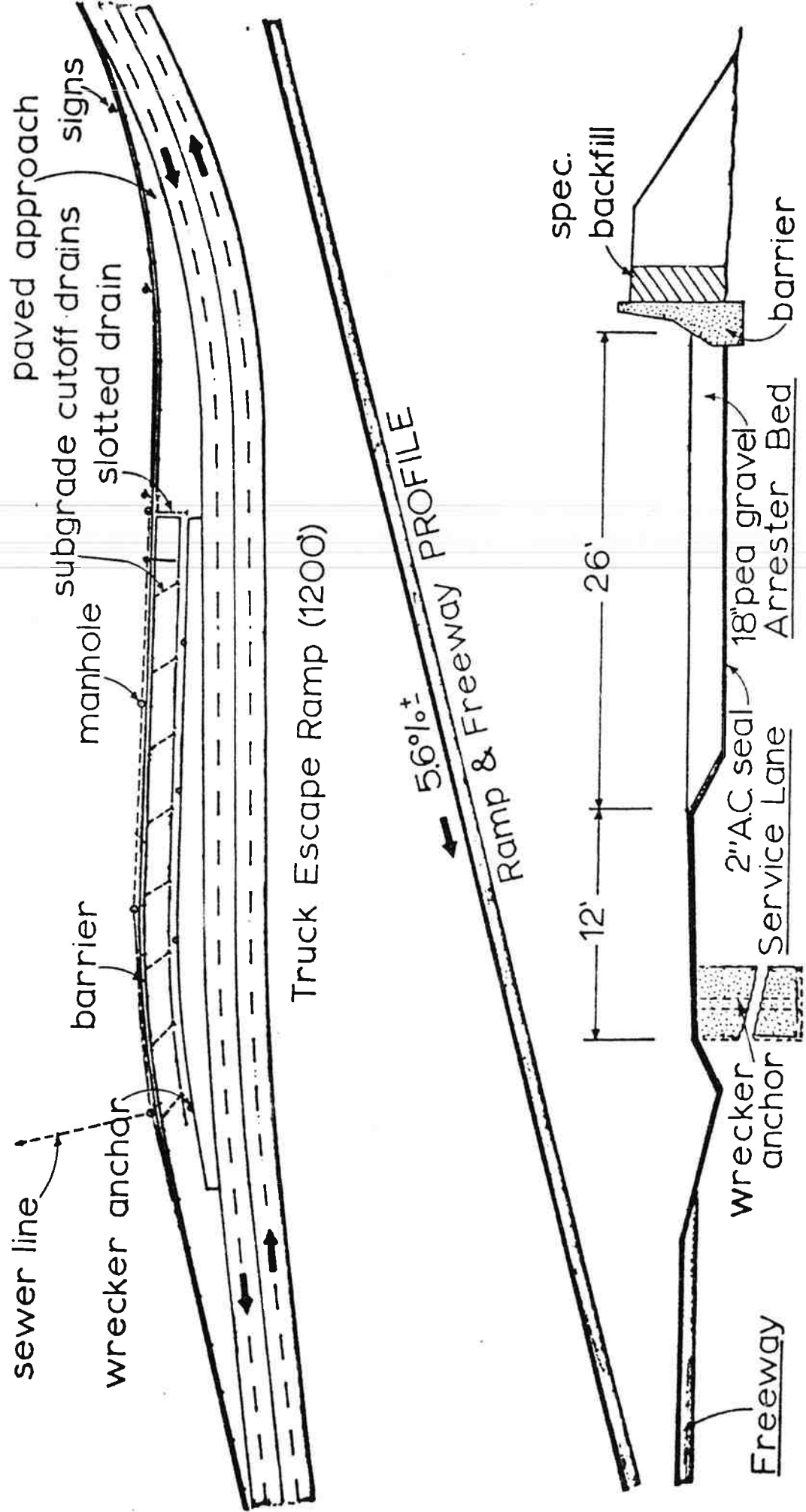
1. to determine if a gravel arrester bed could stop trucks on a descending grade;
2. to further test the effects of transverse mounds on vehicles using the escape ramp;
3. to determine if the coefficient of rolling resistance varies with the load and velocity of the test vehicles; and lastly,
4. to collect data from several years of in-service use of the escape ramp.

The testing was conducted December 5 through December 9, 1977, at the nearly completed 1200' long, 26' wide escape ramp (see Figure 2). The weather conditions were cool and cloudy; temperatures were mostly in the 30's and low 40's with occasional light rain. There was a thin crust of frost on the arrester bed the morning of December 8, 1977.

Three test vehicles were employed. Two vehicles, a Ford and a Dodge, were five cubic yard, two-axle dump trucks. The third vehicle, an International tractor and a flat bed trailer, had a combined five axles. There were two load conditions for each truck, empty and full. For the loaded conditions the dump trucks were filled with gravel, and the flat bed was equipped with a water-filled rubber bladder. The test driver would accelerate the vehicle to the nominal entry velocity, enter the ramp maintaining this velocity and then disengage the clutch just prior to entering the arrester bed. He attempted to steer a straight course down the bed, but no other actions were taken. The brakes were not used and the clutch remained disengaged. Three nominal initial velocities were tested: 25, 40 and 55 mph. These were driver-maintained velocities, checked by radar.

Thirty-eight trials were run; thirty-three on a smooth arrester bed, and five with mounds or terraces. These included one trial with the left side of the truck intentionally driven on the paved access road, three trials with the transverse gravel mounds (two with a one foot high mound located 20 feet from the beginning of the bed, and one with four one-foot-high mounds located at 20, 53, 86 and 119 feet) and one trial on a terraced bed with one foot drops at 20 and 72 feet.

OREGON



FIELD DATA

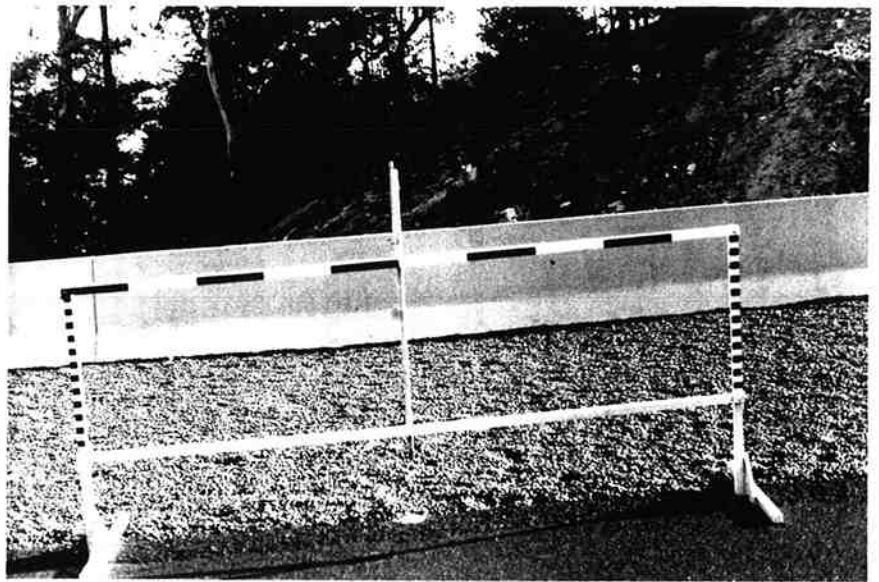
The initial velocity was measured using two radar units, one located near the beginning of the arrester bed and one further down the bed. The distance between the start of the bed and the front axle of the stopped vehicle was recorded. This measurement was later corrected to the vehicle's center of gravity.

Pictures were taken of the trial runs by four 16mm motion picture cameras located along the fog line of the main highway at varying distances from the start of the bed. Wooden targets with alternating white-black, one-foot-long sections and vertical target bars were placed between each camera location and the bed. A matching rod was attached to the side of each vehicle. By measuring the distance the test vehicle traveled past the vertical target bars during a set number of movie frames, the local velocity was calculated at each camera location. (See Figure 3, a set of photographs showing the testing procedure.) Comments concerning each trial were recorded where appropriate. (Appendix, Table A summarizes the results from the thirty-eight experimental tests.)

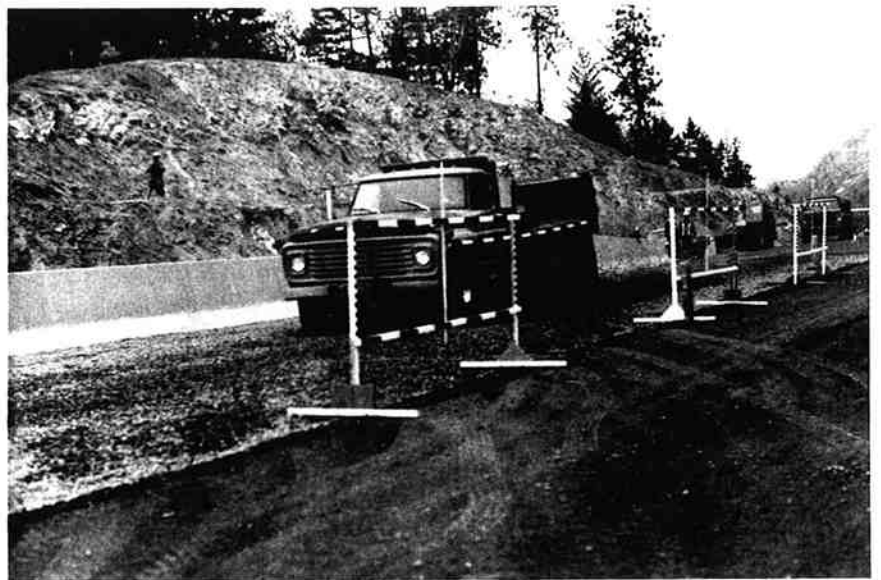
Because of damage to vehicles and unsafe vehicle reactions, trials with mounds and terraces were discontinued before enough data was collected to confirm that these features increase vehicle deceleration. Only trials nineteen and twenty-six, at 25 and 26 mph with one mound, were completed without damage to the vehicles.

In all of the experimental trials, the test vehicles stopped far short of the end of the arrester bed. The longest required stopping distance was 484 feet, which occurred when the empty 5-axle International entered the ramp at 55 mph. Although it was anticipated that in actual usage trucks may enter the ramp at velocities up to 80 mph, for safety reasons testing velocities were held to under 60 mph. Therefore, it was necessary to extrapolate stopping distances at the higher velocities in order to determine the adequacy of the escape ramp.

Wooden target with alternating white-black one foot long sections and vertical target bar.



Empty five yard dump truck entering ramp.



The pea gravel bed can damage vehicles.



International flatbed with
water-filled rubber bladder
entering gravel bed at
40 mph...



...and "arrested"
approximately 215 feet
into the bed.



Vehicles must be towed out
of the bed.



The rolling resistance factor, 'F', was averaged over each run, using initial velocity and total stopping distance. The following equations were used in the calculations:

$$F = \frac{V_i^2}{29.9d} + 0.055$$

where:

$$d = \frac{V_i^2 - V_f^2}{2a}$$

$$a = (G + F)g$$

d = total stopping distance (feet)
 Vi = initial velocity (fps converted to mph)
 Vf = final velocity (0 mph)
 a = acceleration WITH DECELERATION POSITIVE
 G = grade with downgrade negative = -0.055
 F = rolling resistance
 g = gravitational constant

The F values were then grouped into the following four categories: empty two-axle, loaded two-axle, empty five-axle and loaded five-axle. A linear regression was conducted with the data in each category (see Appendix, Figure 4). Using F-values extrapolated to 80 mph, the following stopping distances were calculated:

Vehicle	F	D(80) in feet
empty 2-axle	.25	1100
empty 5-axle	.24	1175
loaded 2-axle	.32	810
loaded 5-axle	.26	1040

These calculations show that the 1200' arrester bed has adequate length to stop all of the test vehicles at an 80 mph entry velocity. Figure 4 shows that the arrester bed did not cause a constant deceleration in all trials. The run averaged F-values varied with vehicle type, axle load and initial velocity. The two-axle trucks had higher values than the five-axle trucks, the loaded trucks had higher values than the empty trucks and low initial velocities had higher values than high initial velocities.

The motion picture film was analyzed frame by frame to determine the local velocities and decelerations of the test vehicles at several points during each run. This analysis was difficult because of distortion of the measuring rod attached to the test vehicles and the fact that measurements were taken at only two or three locations during each trial. However, the results do show a definite increase in rolling resistance as the test vehicles slowed during an individual trial (see Appendix, Figure 5).

The general trends in the relationships among velocity, axle load and F-values as shown in Figure 4 seem reasonable. Heavier axle loads and slower speeds should allow deeper penetration of the wheels into the gravel, thus causing greater resistance. However, the low correlations for the linear regression analyses emphasize the amount of scatter in the data. There were characteristics in each trial that were not easily quantifiable, such as the amount of bouncing, steering corrections, and the path traveled. These undocumented parameters make it impossible to specify the exact nature of the velocity vs. F-value and the axle load vs. F-value relationships.

INSERVICE DATA

The Siskiyou Summit Truck Arrester Bed was completed and opened to the public in February 1978, and over four years of data are summarized in the Appendix, Figure 6. The longest stopping distance recorded was 1050 feet by a tandem trailer estimated to be traveling 85 mph. The load was lost off the second trailer, causing it to sway, but it did not overturn. There were several penetrations of more than 900 feet, one of which had an estimated 100 mph entry velocity.

There have been two instances of a truck overturning while using the escape ramp. In one, with an entry velocity of 55 mph, the driver was uninjured, but he was unsure what had caused the overturning. A vehicle had been removed from the bed earlier that day and the maintenance crew had not been contacted to smooth the ramp. The overturning may have been caused when the truck crossed the earlier truck's wheel tracks.

The second overturning, with an entry speed of 80 mph, was the only incident of an injury during use of the ramp. The truck struck the concrete barrier, flipped the cab on its side and the driver received lacerations and broken bones.

The inservice data were both difficult to collect and interpret. Most legitimate users of the escape ramp were not interviewed. Many times the only evidence of ramp usage was wheel tracks that were left after an unknown vehicle entered the bed at an unknown velocity for an unknown reason. Even when the driver was interviewed, the data gathered were of questionable quality, especially estimates of entering velocity. No data were collected on the use of brakes or transmission after entering the bed.

Nonemergency use has been a major problem at the Siskiyou truck escape ramp. Unauthorized use presents not only a hazard, the ramp being blocked when needed by a runaway truck, but also an additional expense since the bed must be smoothed after each use. Unfortunately, the ramp is located just above a rest area. Many drivers have pulled onto the ramp and have become stuck thinking they were entering the rest area. Three signing modifications have reduced the problem, but still people enter the bed thinking it to be an exit. Drivers of recreational four wheel drive vehicles often enter the bed to see if they can traverse it. They usually succeed, leaving the wheel tracks for the maintenance crew to smooth. In the first nine months of operation, March through December 1978, only 25 percent of escape ramp entrances were by legitimate users.

Appendix Figure 7 indicates a reduction in efficiency of the arrester bed over time. The increase in stopping distances is thought to be caused by compaction of the bed through settling and contamination from the sand used to improve traction on the main highway during snow and ice conditions. Because of this, in 1982 the gravel in the first 600 feet of the arrester bed was removed, rescreened and replaced.

RECOMMENDATIONS

Using the results of this study to determine design lengths for other arrester beds should be done with caution. The F-values are site - specific, particularly because they depend upon the size and gradation of the gravel used in the arrester bed. Although the empty 5-axle test vehicle had a lower F-value and therefore a greater stopping distance, using this data would result in an overly conservative length for the bed. An empty vehicle is less likely to develop overheated brakes and, although probably driven at higher speeds on the downgrade, the absence of a single reported occurrence of an empty runaway truck using the escape ramp confirms the advisability of using the loaded 5-axle F-values for design purposes.

Performance of the truck arrester bed has been excellent. Since its construction, only two reported truck accidents have been reported, and these occurred above the ramp. This project resulted in the negative grade arrester bed being adopted as a primary standard in Oregon State Highway Specifications.

The following recommendations are made for aiding in the design of a negative grade arrester bed. These recommendations are based on test results, research and inservice data.

- 1) Descending truck escape ramps should be utilized only when ascending ramps are not feasible. When access is easily available, ascending ramps are more effective and economical.

- 2) Adequate signing is important to prevent unauthorized use because of the danger of a runaway truck hitting a vehicle stuck in the bed or overturning when hitting wheel tracks. Also, extra expense is incurred when maintenance crews have to be sent to smooth wheel tracks caused when drivers mistake the escape ramp for an exit ramp or a rest area.
- 3) Terraced beds or beds with transverse mounds are not recommended because of possible vehicle damage and possible loss of control of the vehicle.
- 4) A paved service ramp alongside the arrester bed is necessary to allow tow trucks access to pull trucks from the bed. Tie downs to anchor the tow trucks should be provided at least every 300 feet along the service road. These anchors should be placed off the edge of the service ramp away from the arrester bed in order to provide the proper angle to pull trucks out of the bed and onto the service road. One anchor needs to be placed at the 150 to 200 foot distance to assist in removing trucks which have entered only a short distance into the bed.
- 5) The effectiveness of the arrester bed is highly dependant upon the condition of the gravel. Adequate drainage combined with proper gradation is needed to prevent the bed from freezing solid. Records and inspections should be used to determine if contamination or compaction requires the bed to be rescreened.
- 6) The beginning of the arrester bed should taper gradually to full depth. A 30 foot transition is suggested to prevent the vehicle from bouncing when it drops off the pavement into the gravel. It is also important that the bed be aligned so that the front wheels enter the bed simultaneously.
- 7) The twenty-six foot width of the Siskiyou escape ramp is wider than necessary for one vehicle, and although several incidences of dual usage have been reported, it is recommended the ramp be widened to thirty-six feet if designing for dual use, or narrowed to eighteen feet for single use.
- 8) An escape ramp which cannot handle a second vehicle should be marked as occupied far enough before the ramp to warn approaching trucks and prevent a second entry.
- 9) If the escape ramp is to be used while covered with snow, the edges of the ramp must be marked to ensure the vehicle enters the gravel bed and not the paved service road.

APPENDIX

Table A.....	Summary of Tests
Figure 4.....	Linear Regression
Figure 5.....	Instantaneous Velocity vs Instantaneous "F" Value
Figure 6.....	% of Vehicles Using Ramp by Stopping Distances and Number of Vehicles Using Ramp by Stopping Distances
Figure 7.....	Average Stopping Distance by Year

TABLE A

Form 734-3049 (Rev. 2-79)
OREGON DEPARTMENT
OF TRANSPORTATION

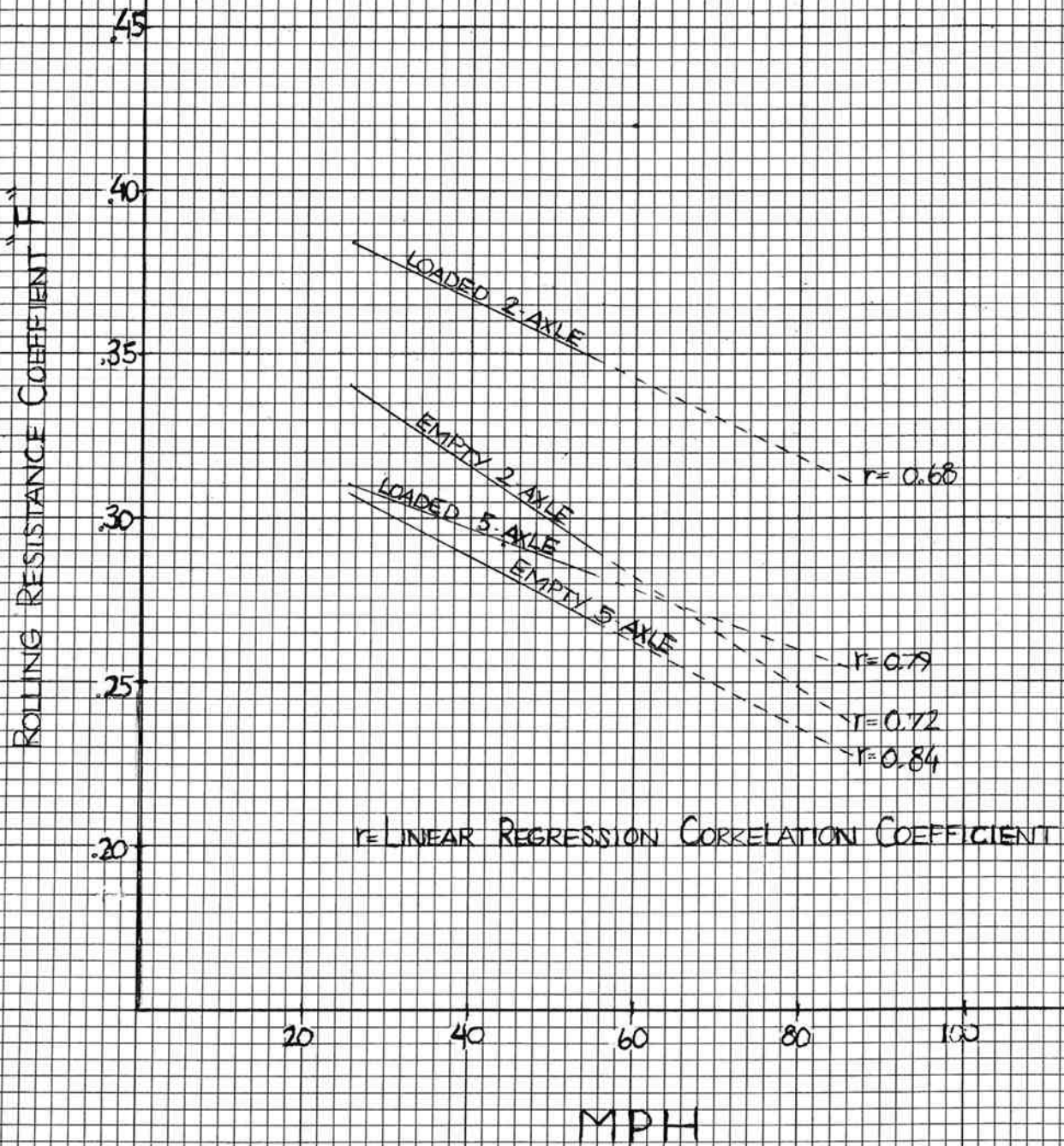
TABULATION SHEET
SHEET 1 OF 2 SHEETS

TEST DATA

RUN	VEHICLE	INITIAL VELOCITY (mph)	STOPPING DISTANCE (feet)	"F"	---	COMMENTS	---	
1	E. FORD	26	77.8	0.346	Driver had	no steering,	truck pulled	hard
2	E. FORD	25	78.4	0.322	to left.	Pulled to	left	
3	L. FORD	25	62.1	0.392				
4	L. FORD	25	65.6	0.374				
5	E. FORD	36.5	187.6	0.293				
6	E. FORD	39.5	219.6	0.293				
7	L. FORD	38.5	164.6	0.356	Truck bounced	excessively,	broken tie rod	
8	E. DODGE	40.0	189.1	0.338				
9	E. DODGE	50.5	331.6	0.312				
10	E. DODGE	55	456.6	0.277				
11	E. DODGE	26	76.6	0.350				
12	E. DODGE	25	69.6	0.355	Aggregate added	at front of bed,		
13	E. DODGE	57	445.6	0.299	less bounce			
14	L. DODGE	26	72.6	0.366				
15	L. DODGE	25	57.6	0.418				
16	L. DODGE	41	177.6	0.372				
17	L. DODGE	52	302.6	0.354	Some bouncing			
18	L. DODGE	54	323.6	0.356	Some bouncing			
19	L. DODGE	25	62.4	0.390	1 mound at	20 feet		
20	L. DODGE	40	126.4	---	4 mounds, tie rod and	axle damage,		
					truck hit barrier			

TEST DATA, PAGE 2

RUN	VEHICLE	INITIAL VELOCITY	STOPPING DISTANCE	"F"	-----COMMENTS-----		
21	L. FORD	26	--	--	2 terraces, vehicle damaged		
22	E. FORD	40	186.6	0.342	Aggregate frosty		
23	L. FORD	40	183.1	0.347	Not a straight run		
24	L. FORD	26	84.1	0.329	Vehicle entered with left wheels on paved service ramp. Violent pull to right.		
25	-----data unclear-----						
26	L. FORD	26	61.6	0.422	No damage with 1 mound, 1 foot high at 20 feet		
27	E. SEMI	28.5	103	0.319	Tractor dug in, trailer pushed		
28	E. SEMI	28.5	112	0.298			
29	E. SEMI	39.5	226	0.286			
30	E. SEMI	40	239	0.279			
31	E. SEMI	48	339	0.282			
32	E. SEMI	55	464	0.273			
33	L. SEMI	28	108.6	0.296			
34	L. SEMI	27	93.1	0.317			
35	L. SEMI	41	232.6	0.297			
36	L. SEMI	40	215.6	0.303			
37	L. SEMI	53	413.1	0.282			
38	L. SEMI	54.6	360.5	0.331	Broken walking beam, bouncing		
		Semi was	5-axle tractor and flat bed trailer				
		Ford and Dodge were	2-axle dump trucks				
		L = Loaded					
		E = Empty					



INITIAL VELOCITY
VS

RUN AVERAGED F-VALUES

FIGURE 4

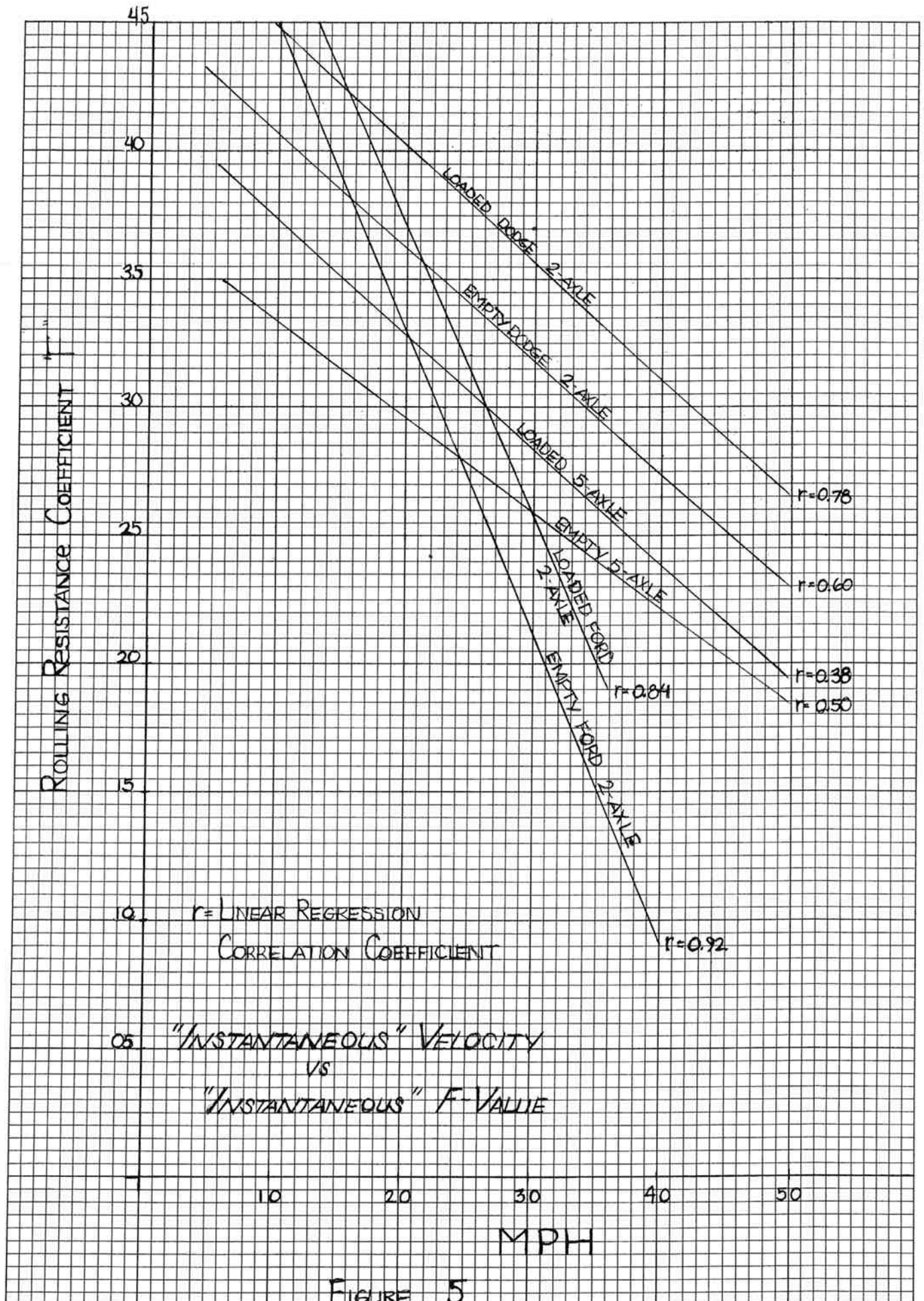
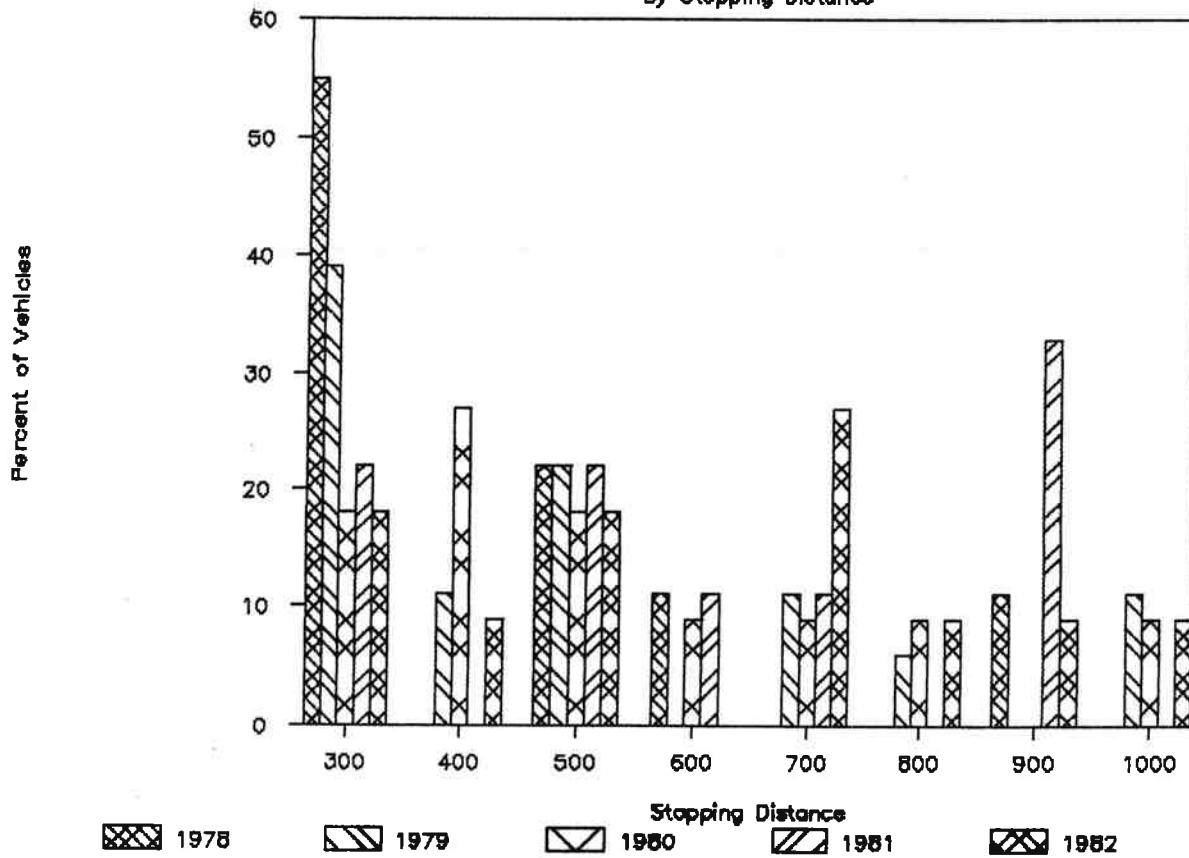


FIGURE 6

Percentage of Vehicles Using Ramp

By Stopping Distance



Number of Vehicles Using Ramp

By Stopping Distance

